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Relay Aided Maritime Broadband Network

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ABSTRACT

The geographical and environmental constraints it is usually not reliable to provide high data rate wireless broadband access to the mariners in the deep sea. This limitation can be settled by introducing the multiple input and multiple output (MIMO) relay assisted maritime wireless network that can extend the reach of internet to the ships deep into the sea. The design challenges are many-fold. However, the focus would be on developing signal processing based theoretical model for a linear MIMO transceiver with perfect channel state information (CSI) utilizing amplify-forward (AF) relaying with maximum range and capacity. The novelty is in utilizing multiple relays cooperatively where spatial multiplexing both at transmitter and receiver would enhance diversity. The ZF based theoretical model so developed will be more helpful to reduce the interference effect.

Keywords: *Dual-hop, CSI, Evaporation Duct, MIMO, Maritime communications, Zero-forcing*

1. INTRODUCTION

Customarily, the telecommunication between sea users is taken place through the costly satellite services of the unavailability of cost effective wireless service over the sea. In maritime environment to extend the terrestrial wireless coverage with high capacity, range and best QoS at acceptable is demanding. The deployment of wireless access system into this environment with less cost has become attractive. The major part of earth is enclosed by the sea and more than nighty percent world's merchandises is transported through merchant marine utilizing several ships. Therefore efficient and reliable maritime broad band communication systems can play a significant part in maritime operations [1].

The modern communication technologies have boasted up the rapid development in wireless broadband terrestrial networks. Broadband Internet for Maritime is available but through Satellite (VSAT), that has extended high speed connectivity, wherever and whenever terrestrial network cannot operate. At present ships in deep sea are using broadband via satellite at data rate of 512Kbps to 4Mbps at high cost. Terrestrial wireless broadband is available for maritime but in the LOS up to 4 km in the sea [2].

Table.1 Table of Specification

Wireless Standard (WLAN)	IEEE 802.11
Frequency	10.6 GHz
Distance to be Covered	78 KM
Path loss at 10.5 GHz	141 dB
Transmitter and receiver antennas height above the sea level	5 m
Transmit power	27 dBm (500 mW)
Gains of transmitter and receiver antennas	40 dB
Noise temperature of antenna	300 K
Bandwidth	14 MHz

The employment of a high capacity broadband, over ocean under evaporation duct has been investigated in [2]. Table 1 represents the feasibility of the work in [2] for world's largest marine part the Great Barrier Reef (GBR) in Australia.

In [2], the high capacity data link was proposed using evaporation duct channel where the height of antennas and optimum operating frequency was determined. A Maritime Ad hoc network is a form of mobile ad hoc network to integrate the communication between ship-to-ship/shore. This project considers boats/ships and nearby fixed stations, such as oil platforms at sea and base stations on ports, as nodes in a maritime ad hoc network. Each boat with MANET device will be a node, the nodes can communicate each other directly that are within the radio range, while distant terminals communication depend on adjacent terminals to forward information. Basically, the idea of the ad hoc network for ship-to-ship/shore at the sea is that the boats/ships can communicate directly with each other within transmission coverage, otherwise communicate on multi-hop [3]. For this we will have to consider a linear link between source and destination. Our focus is dual-hop multi relaying network for shore to shore/ship communication.

There are a lot of challenges to establish a mobile wireless network for communication between ship-ship/shore on ad hoc basis. A lot of problems are faced in sending the signals over the rough sea environment for beyond LOS (line-of-sight) communication between ship-to-ship/shore-to-shore [4]. The aim is to establish a linear Maritime dual-hop multi-relay MIMO network for broadband wireless communication between shore-to-shore/ships or ship-to-shore. Multi-hop communication practice benefits in 1) increases coverage of the source to the uncovered area or black hole and 2) with the use of spatial diversity it helps to control the wireless channel limitations [5].

The relay-assisted dual-hop cooperative transmission has received a lot of research interest that can improve the system performance efficiently. Standardization efforts have also been made to incorporate multi-hop relaying into third-generation

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mobile communication systems. Wireless communication systems adopting relays have recently attracted attention due to their potential to improve the signal reception quality significantly, when the direct communication link between the source and the destination is long and not reliable due to the faded and scattered nature of the channel, particularly the challenging and time varying nature of rough sea evaporation duct used as the wave guide for signal propagation from source to destination over the sea [5].

The proposed system would like to design a linear transceiver for dual-hop non-regenerative multi-relay for MIMO system for marine network as shown in Fig.1. The rough sea evaporation duct (RED) channel is used for maritime networks. The specifications of the network are as stated in Table 2. The choice of 10.5 GHz as the carrier frequency is to facilitate propagation through evaporation duct. The IEEE 802.11n standard is useful for various network protocols. The physical layer uses MIMO with relays located at about 70 km for source to destination distance of 150 km [5].

Our assumption is that by making the use of multiple relays cooperatively such that, instead of causing ISI, they contribute to SNR at receiver the system performance can be improved. This is done by a suitable MIMO beamforming for spatially multiplexing the data to multiple relays and also using MIMO beamforming, so as to spatially multiplex the data from multiple relays at receiver for diversity gain. This would enhance the range and capacity with simple AF relays. The study would explore using multi hops for the purpose. The optimality is in terms of minimizing MSE, which, in turn, maximizes channel capacity [6].

Table.2 Specifications table for the proposed system

Wireless Standard	IEEE 802.11n
Wireless Medium	MIMO-OFDM
Frequency	10.5 GHz
Data Rate	> 10 MBps
Distance to be Covered	> 150Km with dual hop can be increased by adding number of hops
Relays	Multi-Relay System
Relay Scheme	AF

IV. Evaporation Duct Over Sea Surface

The propagation of radio wave over the sea surface to establish a relay based wireless broad communication can be of great significance. The evaporation duct over the sea surface is approximately undying propagation setup due to the sudden variations in the upright temperature and humidity profiles. The probability of presence of the evaporation duct (is a narrow surface created over sea surface) is above eighty percent and its average height which varies between 7-15 meters and where quoted as between 6-40 meters [7]. It is published that in the month of March, April, September and November the height is up to 25-40 meters [8]. The atmospheric duct is developed with the conformation of pressure, temperature and humidity. It is higher over tropical sea and affects the radio signals from 1-20 Giga Hertz [8]. The height is calculated by using fundamental techniques such as LKB, RSHMU, ECMWF and COARE models . The evaporation duct statistics of height help to design a maritime wireless microwave communication .

It would be very hard to make the information transmission system over the sea surface in normal refractive conditions is problematic, therefore shore to ship microwave broadcast systems on the sea surface is limited. The MIMO and relaying systems with MIMO can be efficient solution to these limitations. A great amount of successful research is carried out through experimental measurements for investigating the evaporation duct channel characteristics in the marine environment.

Critical research challenges to enhance the performance of Maritime Relay Network would be to maximize the range and maximize capacity, while maintaining high throughput and reliability under highly fading maritime channel. Though the dual-hop multi-relay network design as shown in Fig.1 has not been attempted for the maritime network.

II. MIMO Technology

When multiple antennas are used to transmit the information signal at the transmitter and receiver of the wireless node then the system is said to be the multiple input and multiple output system. This technology provides the diversity gain at transmit as well as at the receive side and reduces the fading effect of the channel by sending the multiple copies of the information signal by the multiple antennas [11].

III. Cooperative Relaying Technology

From the tele-communication and particularly wireless communication perspective the cooperation holds a number method that jointly and collaboratively utilizes the resource for better performance of the system. The cooperation is established various levels comprising signal processing, method and interoperation of the technologies. The cooperation relaying and MIMO technologies is more attracted by the modern communication system for the networks of the future [11]. The cooperative relaying protocols commonly used in wireless communication system are transparent and non-transparent relays, which are non-regenerative and regenerative relay. In non-regenerative relays the signal received is just amplified and forwarded to the desired point and in regenerative relays the received signal is decoded and then after encoding it is forwarded to the intended node. The non-generative relays are more popular due to low complexity as compared to the regenerative relaying protocols and are widely used with MIMO technology in various network configurations and systems [12, 13].

V. SYSTEM MODEL

The dual-hop non-regenerative multi (L)-relay maritime wireless broadband system is shown in Fig.1. It consists of N_S Source antennas; M_R receiving antennas at relays N_R transmit antennas at relay and M_D destination antennas. At first hop the source transmits data to relays and the received signal x_k at relay on the k^{th} subcarriers is given by

$$x_k = B_t H_{sr} s_k + n_{1,k} \quad ,k = 0,1, \dots .K-1 \qquad (1)$$

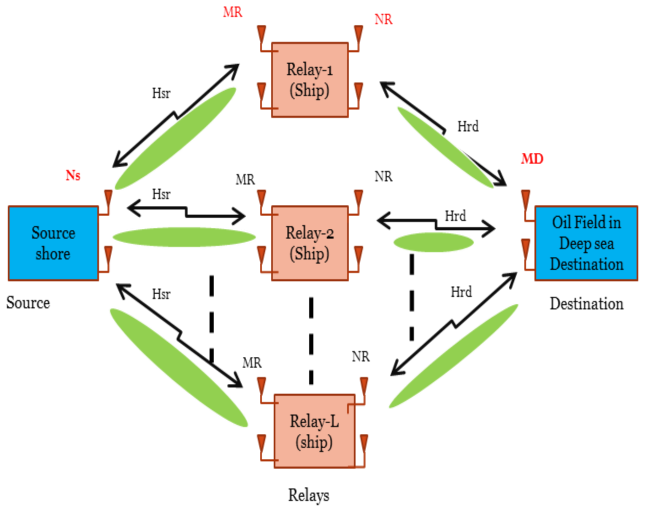

Figure.1. Dual-hop multi-relay maritime network

Where H_{sr} is set of channels from transmitter to relays and B_t is transmit beamforming matrix. The received data y_k at the destination on kth subcarrier is;

$$y_k = B_r H_{rd} F_K B_t H_{sr} s_k + B_r H_{rd,k} F_k n_{1,k} + n_{2,k} \quad (2)$$

Here k^{th} subcarriers, F_k, forwarding matrix, G_k is linear equalizer, $Tr\{.\}$ is the trace of matrix, B_r is beamforming matrix at receiver, arbitrary covariance matrix P_r is the maximum transmitted power, H_{sr} and H_{rd} are the channel matrices from source-relay and relay to destination respectively. The notation x_k is signal received at the relays, s_k is the data sent by by the source, where $n_{1,k}$ and $n_{2,k}$ are the additive Gaussian noise with zero mean and covariance The symbol E{.} represents expectation operation [13]. It is assumed that full channel information is available at the ship based relay nodes which are moving the deep sea. A popular interference mitigation technique termed as zero-forcing technique is applied at the relay node for relays receive and transmit beamforming [15].

Channel Inversion based signal processing for relay aided maritime network

The channel inversion is actually the pseudo inverse of the channel matrix also termed as the zero forcing beamforming that is given as [11];

$$F_k = H_{sr}^H (H_{sr} H_{sr}^H)^{-1} \qquad (3)$$

Here, F_k is the beamforming matrix for the relay reception, similarly the same signal processing is applied to the relay transmit signal known as the relay transmit beamforming.

Another technique is adapted here is the matched filter (i.e H_{sr}^H) of maximum ratio transmission (MRT) is which used at the relay receive signal processing, that can help to increase SNR at the relay reception.

VI. RESULTS AND DISCUSSION

The simulation results are presented using MATLAB. Two well-known techniques (channel inversion and matched filter) are adapted to design the signal processing of the relay reception and transmission side. In the system configuration as in Fig.1 it is considered to have a source (base station) at the sea shore and destination node is at any oilfield in the deep, the multiple relays will help to establish the communication between the shore node and destination node in the deep sea. The multiple relays are incorporated in such a way that they are connected in parallel

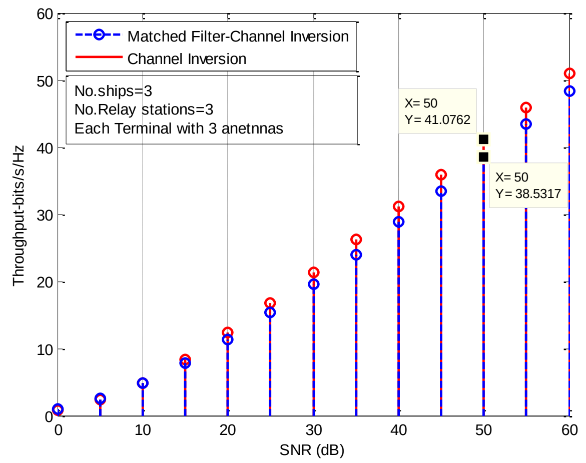

Figure.2. Throughput vs signal to noise ratio

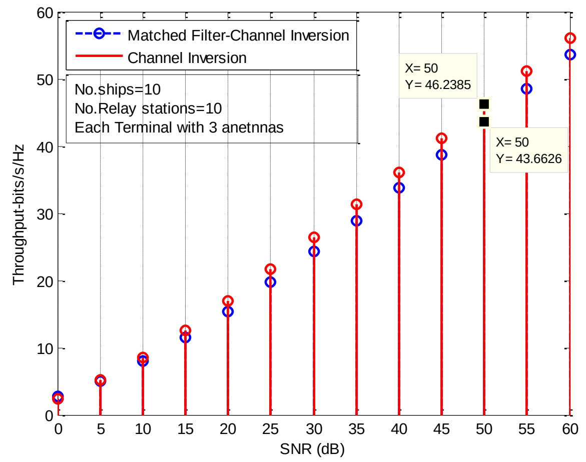

Figure.3. Throughput vs signal to noise ratio

The Fig.2 shows comparison of achievable rate of the two techniques zero forcing used at the relay receive and transmit beamforming and another scheme where Matched filter is used as the relay receive processing and zero forcing at the relay transmit processing. In this setup three relays are considered and every node including source and the destination has three antennas. The stem diagram of Fig.1 shows that the data achieved through channel inversion scheme is much better than the scheme matched filter and channel inversion together. It can be seen in the figure that at high SNR values the performance of channel inversion scheme only has better output as compared to matched filter and inversion scheme. The matched filter only performs well at low SNR values. If we see the stem point at 50 SNR value data rate obtained with channel inversion is 41b/s/Hz, whereas other scheme has 38 b/s/Hz with this configuration.

Similarly, the Fig.3 represent the data rate achieved using both schemes respectively. In this simulation the number of relays is considered as ten with three antennas at each node and the range of SNR is from 0-60 dB. From this configuration there is an increase in data rate due to distributed array gain obtained from the increased number of relays node deployed at various ships. The increase data rate as compared to the Fig.2 is almost 5 b/s/Hz.

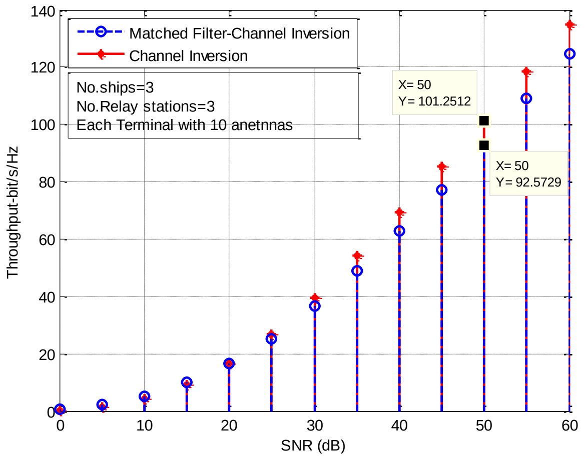

Figure.4. Throughput vs signal to noise ratio

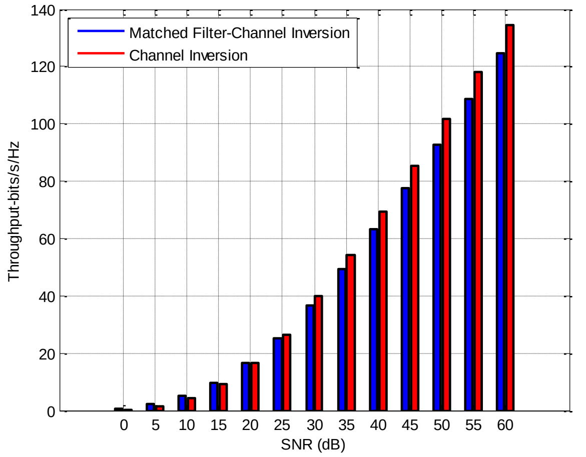

Figure .5. Throughput vs signal to noise ratio in bar graph

In the results of Fig.4 we have used 10 antennas at each node and 3 relays on the three ships are considered. If the performance of this configuration is compared with the results shown in Fig.2 and Fig.3 respectively, then there is large increase in data rate due to the large number of antennas at each node. The channel inversion is still providing better results. The similar data growth is represented in the Fig.4, it is validated that the more MIMO antennas provide the diversity gain and more relay connected in parallel can provide distributed diversity gain.

The objective of this research is evaluated by establishing a simulation based shore to ship maritime relay network with dual hop multi-relay MIMO system. To test, evaluate and validate the performance in terms of Capacity.

VII. CONCLUSIONS

The proposal for designing the relay assisted maritime wireless broadband network using evaporation duct channel as the communication link that is already have been modeled and found effective channel for wireless communication system over the sea surface. The relaying and MIMO technologies based network can be more efficient and cost effective solution to provide broadband service to the ships in deep sea as an alternate service of the satellite communication. In this direction there a lot capacity to design the signal processing schemes using evaporation duct channel characteristic from the practical point of view. The multi-relay based scenario can be suitable for inter-ship broadband communication network to provide distributed diversity gain.

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List of Abbreviations

Abbreviation	Description
LKB	Liu-Katsaros-Businger
RSHMU	Russian State Hydro-Meteorological University
ECMWF	European Center for Medium range Weather Forecast
COARE	Coupled Ocean-Atmosphere Response Experiment
RED	Rough Sea evaporation duct
MANET	Marine Network
LOS	Line of sight